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Mid-Frequency Ambient Noise Spatial Structure and Implications for Passive Signal Processing

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14. ABSTRACT

The purpose of this 3.5-year project was to investigate experimentally the time-evolving spatial distribution of ocean ambient noise and signals in the 1-10 kHz frequency band using multi-element hydrophone arrays with very high resolution in the vertical direction. These measurements were used to guide the development of algorithms for passive signal/array processing that were effective in detection, localization, and tracking of quiet submerged sources of interest.

15. SUBJECT TERMS

acoustic, signal processing, ambient noise, localization, hydrophone arrays

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* A high degree of anisotropy exists in the vertical spatial structure of the mid frequency noise field; up to 20 dB in the vertical direction and up to 10 dB in azimuth in the horizontal direction in the absence of discrete noise sources such as nearby ships.

* Although the level of the noise notch in the horizontal direction can be as much as 20 dB below that at higher angles during daytime periods, the level in the horizontal can exceed that at higher angles by as much as 10 dB at night. This horizontally-arriving energy, composed of two broad peaks centered at 1.5 kHz and 5 kHz, shows no short-term temporal variability. The sounds come from the direction of a popular Southern California fishing spot and occur almost exclusively on two consecutive nights corresponding to a full moon. They probably are due to the nighttime sounds of some species of fish (possibly due to tail cavitation since the frequency content is quite high for swim bladder resonances) or invertebrate (sea urchins are known to participate in a chorusing behavior).

* Numerical modeling of the MF wind-generated ambient noise field using the Navy standard model CASS/GRAB indicate the vertical spatial structure is sensitive to the depth of a near-surface noise sheet, to changes in bottom properties (MGS bottom province 1 provides best match to data), and to sound speed profile. Although sources to a maximum range of 3-5 km contribute most significantly to the vertical structure in range-independent media, contributions from bathymetry features at 20 km or more can fill in the horizontal noise notch in range dependent environments.

* Although high angle energy may be downslope-converted into low angles of arrival by bottom relief at some azimuths, a deep noise notch typically exists at other azimuths during the daytime.

* The spatially diffuse nature of the source region (distributed in range by more than the mode interference wavelengths) for both biologically and wind-generated noise indicates that the noise field's reactive acoustic intensity is negligible. This property allows for development of detection statistics, including one based on vertical beam-to-beam coherence (see the attached figures).

* The well-filled nature of the 2D billboard array permits the estimation and study of various components of the energetics of the MF acoustic field.

* The noise levels in the horizontal change in lock-step with those at higher angles of arrival when the wind speed changes. This correlation is caused in many cases by coupling of the higher angle energy into lower angles of arrival by the large-scale (larger than an acoustic wavelength of 0.5 m) bathymetric features although, at times, sidelobe leakage plays a role.

* Beamforming results during the active signal transmissions show that the vertical sidelobe level of the billboard array is at least 27 dB down from the main lobe, at least for one time period. However, in-situ calibration over a 7-hour period when the wind speed changed from 4 to 9 m/s, the sidelobe level was only about 15 dB down.

* Very modest horizontal aperture provides greatly improved information on the spatial structure of the noise field using combined conventional/adaptive beamforming.

The main conclusion from the program was that the vertical spatial structure of mid-frequency ambient noise in the ocean provides an increase in signal-to-noise of up to 20 dB for passive detection of quiet targets at depth.

Results from the program were briefed and provided to the Naval Sea Systems Command/ASTO, PEO-USW, for use in their Large Vertical Array program. Some results also were presented to John Schuster, the head of the U.S. submarine security program. A briefing on the program findings later was given to RADM Waickwicz, the head of the Anti-Submarine Warfare Command. Annual reports and formal annual program reviews were provided to John Tague, the program manager at the Office of Naval Research. In addition, we participated in every annual Passive Sonar Program Peer Review and provided John Tague with informal updates on approximately a quarterly basis.

The program results also were presented at scientific meetings and published in various journals and conference proceedings during the period of the program. These included:

G. L. D'Spain and W. S. Hodgkiss, "Mid-Frequency Noise Experiment 2001: Quick-Look Report," TM-469, Marine Physical Laboratory, Scripps Inst. of Oceanography, La Jolla, CA (2001).

G. L. D'Spain and H. H. Batchelor, "Observations of biological choruses in the Southern California Bight - A chorus at mid-frequencies," in press, J. Acoust. Soc. Am., 16 pgs. plus 15 figs. (2003).

J. D. Skinner, G. L. Edmonds, D. E. Ensberg, G. L. D'Spain, and W. S. Hodgkiss, "A high-speed acoustic data acquisition system using mostly COTS components," Oceans 2003 Conf., 6 pgs. (2003).

G. L. D'Spain, J. D. Skinner, G. L. Edmonds, W. S. Hodgkiss, D. E. Ensberg, and R. A. Harriss, "Fine-spatial-scale measurement of the mid-frequency (1-10 kHz) ocean noise field with a vertical billboard array," Oceans 2003 Conference (2003).

G. L. D'Spain, J. D. Skinner, G. L. Rovner, and H. H. Batchelor, "Diurnal variability in the anisotropic nature of ocean's mid-frequency (1-10 kHz) noise field," J. Acoust. Soc. Am., Nov meeting (2003).

G. L. D'Spain, H. H. Batchelor, and L. P. Berger, "Effect of fish(?) choruses and recreational boats on the spatial structure and temporal dependence of the ocean's mid-frequency (1-10 kHz) noise field," Environ. Conseq. of U. W. Sound (ECOUS), (2003).

All project funds were spent at the end of the program. The success of this program led to the present 3-year program titled "High-Frequency/ Mid-Frequency Passive Processing".

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